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Research on Optimisation Methods of Intelligent Building Energy Management System

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Abstract. In recent years, the development of smart building management has gained significant momentum, driven by the increasing need for sustainable development and efficient resource utilization. This demand has led to advancements in technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Supervisory Control and Data Acquisition (SCADA) systems. This paper explores the optimisation methods for Intelligent Building Energy Management System (IBEMS) with a focus on the integration of IoT, AI, and SCADA systems. The study begins by defining IBEMS and its components, highlighting the role of advanced technologies in achieving efficient energy management, improved operational performance, and enhanced occupant comfort. The paper analyses real-time monitoring and automation capabilities and examines how SCADA systems contribute to energy optimization and fault detection. Additionally, the application of multi-criteria decision-making (MCDM) models and activity-based costing (ABC) methods is discussed as a means to enhance the decision-making process and cost management in intelligent buildings. The significance of this study is to explore the optimization of IBEMS to improve energy efficiency, reduce carbon emissions and promote sustainable development. At the same time, it provides real-time energy management solutions that support global environmental goals and advance smart building technologies.

Keywords: Intelligent Building; Energy Management; Artificial Intelligence.

1. Introduction

The rapid urbanisation and industrialisation in the 21st century have led to an increasing demand for energy, making efficient energy management a critical issue [1]. With the building sector being the biggest energy consumer, it consumes nearly 40% of global energy and accounts for 30% of carbon emissions [2]. Therefore, the construction industry, being an important component of energy consumption, has also gained extensive attention [3]. Energy conservation and environmental protection of buildings are inevitable trends in the development of the construction industry. The sustainable development strategy of buildings implies that buildings should be constructed and operated based on reducing pollution, conserving resources, and maintaining ecological balance [4].

In 1988, an intelligent building was defined as one that features an information communication network, enabling the automatic control of two or more service systems [5]. These systems are guided by predictions based on the building's knowledge and usage, maintained within an integrated database [6]. As the integration of advanced technologies in building infrastructure advances, the optimization of IBMES plays a critical role in addressing the pressing challenges of energy efficiency and environmental sustainability. Intelligent Building Energy Management System (IBMES) optimizes real-time energy usage in buildings, reducing unnecessary consumption, and carbon emissions, and contributing to global warming mitigation. It also adjusts environmental settings to meet occupants' needs, enhancing security, quality of life, and satisfaction.

From a structural perspective, the energy system is defined as "all components related to the production, conversion, delivery, and use of energy" [7]. IBEMES, powered by Internet of Things (IoT), enables remote monitoring and control of building subsystems, increasing convenience, and preventing losses. Its broad application boosts operational efficiency, economic benefits, job creation, technological innovation, and industrial advancement, contributing to social welfare and progress. By favoring renewable energy sources, IBEMS supports sustainable energy development and application, highlighting its significant potential and importance for a sustainable future.

2. The Definition of IBEMS

IBEMS is an integrated system that uses advanced technology to monitor, control, and manage multiple subsystems within a building. Integrates various subsystems within a building to monitor, control, and optimize energy consumption. The system utilizes advanced technologies such as the IoT, Artificial Intelligence (AI), and data analytics to ensure efficient energy usage, enhance operational performance, and improve occupants' comfort. As shown in Table 1, the key components of an IBEMS include smart meters, sensors, communication technologies, and energy management controllers, which work together to achieve real-time monitoring, automation, and optimization of energy resources.

Table 1. Components in the IBEMS

Components	Description
Smart Meters	Real-time monitoring and recording of energy consumption, providing accurate data for analysis.
Sensors and Smart Devices	Detecting environmental parameters and device status, providing real-time data.
Information and Communication Technology (ICT)	Data collection, transmission, and processing, enabling interconnectivity of devices.
Smart Appliances	Automatically adjusting operating states to optimize energy usage and reduce waste.
Energy Management Controller	The core of the system, coordinating and controlling various components, executing optimization algorithms and strategies.
IoT and AI	Providing advanced data analysis and automated control to enhance the system's level of intelligence.

By automating energy adjustments and leveraging AI, the system ensures that energy resources are used efficiently. As shown in Table 2, IBEMS features integration, automation, intelligence, user interaction, and communication capabilities, which collectively enhance the system's ability to monitor, control, and optimize energy consumption in real time, leading to improved operational performance and occupant comfort.

Table 2. The features of the IBEMS

Feature	Description
Integration	SBEMS typically integrates a variety of sensors, controllers, and actuators to comprehensively monitor various energy usage within the building.
Automation	The system can automatically adjust energy usage to adapt to changes in the building's internal environment, such as temperature, humidity, and lighting.
Intelligence	SBEMS utilizes AI and machine learning algorithms to analyze energy usage data, predict energy demand, and optimize energy distribution.
User Interaction	The system provides a user interface that allows building managers and users to adjust energy usage settings as needed.
Communication Capability	SBEMS can communicate with other building management systems (such as security systems, and lighting control systems) to achieve more efficient building operations and management.

3. The Role of the IoT and AI in Intelligent Building Management System (IBMS)

An IoT-driven IBMS utilizes a network of intelligent microprocessor-based controllers to comprehensively oversee, manage, and optimize a building's operational systems and services, including HVAC, lighting, electricity, security, and access control. This open-platform system integrates various building equipment into a unified, cohesive database [8, 9]. AI is increasingly being deployed in building environments to facilitate immediate oversight of energy usage, thereby streamlining energy management processes. The adoption of Building Automation Systems (BAS) has expanded significantly across various industries and in the management of large-scale structures, reflecting a growing trend in recent times [10].

Chen et al [8] emphasised the crucial role of integrating IBMS into the core infrastructure of modern buildings, with the increasing prevalence of smart building concepts and the IoT. IBMS are designed to harmoniously blend aesthetics with functionality, creating a comfortable environment while maximizing operational efficiency and minimising energy consumption. In addition to these primary benefits, IBMS also improves machinery and labour productivity, reduces energy costs, and optimises human resource allocation. Zhou et al. [11] proposed a smart energy community management approach that was powered by reinforcement learning, an AI technique. This method employs local energy pools to collect surplus energy from renewable sources. The system operates in a model-free manner, continually refining its decision-making process through the application of the Markov decision process (MDP) and reinforcement learning. The effectiveness of this methodology was assessed through rigorous numerical simulations. Yu et al [12] utilized the Web of Object (WoO) architecture in IoT environments (WISE) for the management of energy in smart homes and buildings. This model is designed to facilitate automatic interaction and collaboration with IoT applications and services. By employing a WoO-based architecture, web-based IoT services and applications are integrated. The methodology leverages service federation and composition to seamlessly blend various services within a network. For smart building energy prediction, an approach grounded in WoO is adopted, with a focus on selecting optimal object attributes.

4. Optimization Method of IBEMS

4.1. Supervisory Control and Data Acquisition (SCADA) systems

SCADA systems play a crucial role in intelligent energy management by providing real-time monitoring and control of energy consumption, environmental conditions, and system performance, enabling prompt decision-making and reducing energy wastage [13]. They integrate various building subsystems for centralized control and automation, optimizing energy consumption and operational costs [14]. Continuous performance monitoring allows early fault detection and proactive maintenance, preventing system failures SCADA also offers detailed analytical reports on energy usage, aiding in trend identification and energy-saving measures. Furthermore, SCADA enhances building security through integration with surveillance and access control systems [14, 15].

Kermani et al [16] used the LAMBDA MG testbed, a microgrid lab equipped with a SCADA system for real energy management projects. The lab's goals are to develop smart infrastructure for the electrical department and to reduce power imports from the main grid through enhanced self-consumption. The SCADA system manages data collection, monitoring, and control, facilitating effective communication and coordination between devices. Real-time and simulation analyses show that the SCADA system minimizes grid energy exchange, aiming for near-zero energy building systems. The implementation resulted in significant energy cost reductions, up to 98% in June, and an average monthly electricity bill reduction of 87%. The initial investment is expected

Figueiredo et al [17] introduced a predictive controller that operates on top of a centralized SCADA system. The SCADA system in this setup consolidates various information streams from the diverse technologies found in contemporary buildings. These include systems for ventilation and temperature regulation, computer networks, lighting controls, and more, as seen in Fig. 1. What’s more, a new comprehensive SCADA-Matlab platform has been developed [17]. It showcases tests for controlling temperature and brightness in large spaces. The controller enhances user satisfaction by meeting their explicit preferences across various user interfaces, all while minimizing energy consumption.

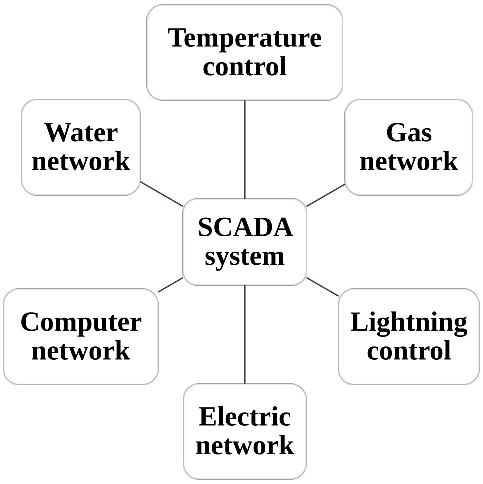

Figure 1. SCADA system as a BAS integrator [17]

4.2. Multi-Criteria Decision Making (MCDM)

MCDM, part of operational research, specializes in optimizing decisions amidst complex situations with multiple indicators and conflicting objectives. It is gaining traction in energy planning for its ability to enable decision-makers to weigh all criteria and goals in a single, comprehensive analysis [18]. The energy system's issues were addressed through a comprehensive MCDM framework. As illustrated in Fig. 2, this overarching framework encompasses six stages: establishing the criteria system, assigning weights to the criteria, identifying alternatives, gathering relevant information, formulating the decision-making matrix, and performing the ranking process [19]. Uzair et al [20] developed an MCDM framework for assisting consumers in identifying resilient and optimal combinations of energy efficiency, cost-saving, and Indoor Environmental Quality (IEQ) improvement strategies for buildings in Pakistan. The model included six costs, cost savings, and environmental impact.

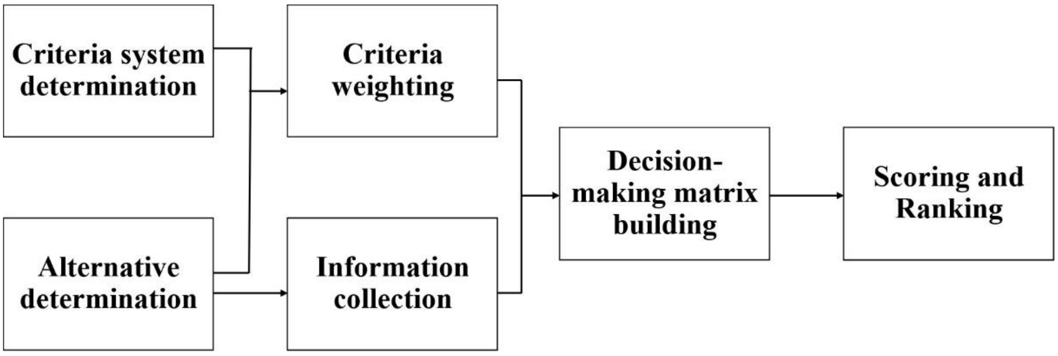

Figure 2. A general framework of MCDM methods [19]

4.3. Activity-Based Costing (ABC)

ABC is a cost accounting method that assigns costs to activities based on their use of resources [21]. It provides a more accurate representation of the costs associated with specific operations within a building. By using ABC, IBMS can identify and analyze the actual cost drivers, enabling more precise cost management and resource allocation. This method helps in understanding which activities consume the most resources and how they impact overall building performance. ABC uses a two-stage process, as shown in Fig. 3 [9]. First, resource costs are traced to activities using resource drivers, which approximate the resource consumption for IBMS construction activities. These activities are grouped into cost pools based on different activity levels (unit, batch, project, and environment). In the second stage, the costs in these activity pools are assigned to cost objects by using activity drivers. The study classifies IBM's costs into direct costs (e.g., materials and labour) and indirect costs (e.g., energy consumption and environmental impacts). This method allows for more accurate cost allocation and better resource management [22].

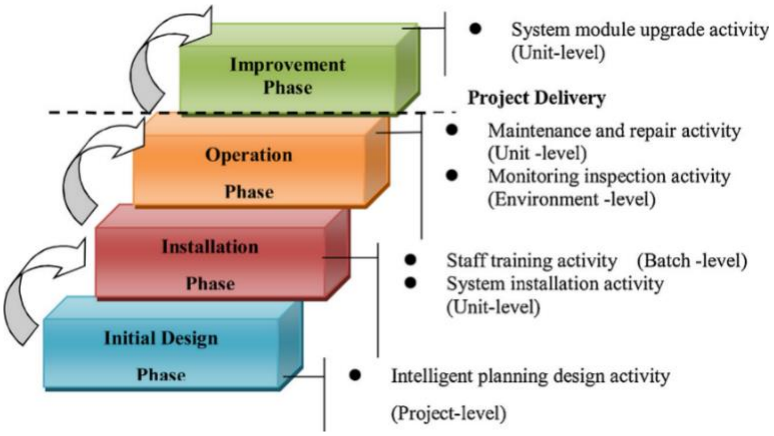

Figure 3. System boundaries for IBMS [9]

5. Conclusion

The research underscores the critical role of IBEMS in addressing the energy efficiency challenges faced by the modern building sector. By leveraging IoT, AI, and SCADA technologies, IBEMS can achieve significant improvements in energy management, operational efficiency, and occupant satisfaction. The case study of the LAMBDA MG illustrates the practical benefits of implementing a SCADA system, including substantial energy cost savings and reduced reliance on external power sources. The adoption of MCDM models and ABC methods further enhances the system's ability to make informed decisions and optimize resource allocation. Overall, this study highlights the potential of IBEMS to contribute to the development of smart, sustainable buildings, aligning with global efforts to reduce carbon emissions and promote environmental sustainability. Future research should focus on the continuous advancement of these technologies and their integration into broader energy management frameworks to maximize their impact . This involves creating adaptive algorithms that utilize real-time data for dynamic energy optimization. Additionally, collaboration among stakeholders like technology providers, building managers, and policymakers is crucial for establishing standardized IBEMS protocols. Integrating blockchain technology can enhance security and transparency in energy transactions, improving trust and efficiency. Finally, incorporating user engagement and behavioural studies will shed light on occupant habits, leading to more effective energy management solutions. It is hoped to enhance further energy utilization and drive overall sustainability in the building sector.

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